

Fuel Cells

U.S. Environmental Protection Agency New England • March 2003

www.epa.gov/ne

Fuel Cells

A fuel cell is a device that produces electricity silently via an electrochemical reaction without combustion. Hydrogen ions from hydrogen-rich sources such as methanol, natural gas, or petroleum are combined with oxygen to generate power. Fuel cells have a very low voltage output, so usually several fuel cells are stacked together to increase the output. Because they operate at almost constant efficiency independent of size, small fuel cells can operate nearly as efficiently as large fuel cells. Applications of fuel cells can vary from small, battery-like portable applications to large-scale power generation to transportation.

How do fuel cells work?

A fuel cell consists of two electrodes, a negative electrode (or anode) and a positive electrode (or cathode), sandwiched around an electrolyte. Hydrogen is fed to the anode, and oxygen is fed to the cathode. Activated by a catalyst, hydrogen atoms separate into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they reunite with oxygen and the electrons to produce water and heat.

Where does the hydrogen come from?

Currently, hydrogen is produced from fossil fuel sources such as natural gas, coal, gasoline, and methanol. For entirely clean and renewable hydrogen extraction, electricity (e.g. from wind turbines) or sunlight captured on solar panels is used to split water into hydrogen and oxygen. However, this procedure is currently too expensive and the technology has not evolved to a point where it can be done on a large scale. Fuel cells can also be equipped with a reformer which will extract hydrogen directly from the fossil fuel source. This process does produce some emissions, but it is still much cleaner and more efficient than the energy obtained from fossil fuel combustion.

The environmental benefits of fuel cells

Because fuel cells produce electricity without burning fuel, they have numerous environmental benefits including:

• Greater Energy Efficiency

The chemical energy of the fuel is directly converted into electricity, reducing the amount of energy needed to produce

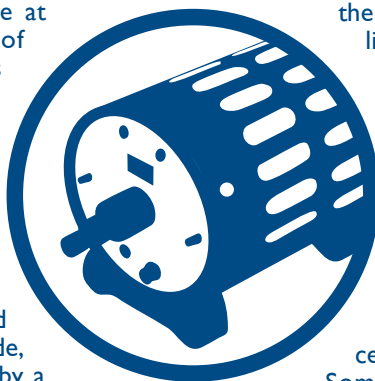
electricity. System efficiency for fuel cells is 30-40%, double that of an internal combustion engine, and 7-10% more efficient than grid power.

• Fewer Emissions

Depending on the fuel used, fuel cells emit a fraction of the CO₂ emitted from fossil fuel fired sources, and little or none of the NO_x, SO₂ and CO.

• Combined Heat and Power

Stationary fuel cells can be used for combined heat and power (CHP) applications, increasing system efficiencies to over 80%.



Types of Fuel Cells

Currently, there are several different fuel cell technologies in use and under development. Some are appropriate for smaller applications, such as vehicles and buildings, while other types of fuel cells may be used for industry and central electricity generating stations. The types of fuel cells currently in use include:

• Proton Exchange Membrane (PEM)

The proton-exchange membrane (PEM) fuel cell uses a fluorocarbon ion exchange with a polymeric membrane as the electrolyte. They operate at relatively low temperatures and are best used in buildings, light-duty vehicles, and smaller applications. They operate with efficiencies of 50-60% and at 50-80 degrees C. PEM cells have fast startup, producing energy almost instantly, even when temperatures are near freezing, and high power density, making them a leading candidate for transportation applications.

• Phosphoric Acid

A phosphoric acid fuel cell (PAFC) consists of an anode and a cathode made of a finely dispersed platinum catalyst on carbon paper, and a silicon carbide matrix that holds the phosphoric acid electrolyte. This is the most commercially developed type of fuel cell and is being used in hotels, hospitals, and office buildings. It can also be used in large vehicles, such as buses. They operate at 55% efficiency, and at 160-220 degrees C. These units generate a significant amount of waste heat which can be used in Combined Heat and Power applications, increasing their operating efficiencies to over 80%.

• Solid Oxide

Solid oxide fuel cells (SOFC) use a thin layer of zirconium oxide as a solid ceramic electrolyte, and include a lanthanum

Links:

Government/ Research Links:

US Dept of Energy, Office of Energy Efficiency and Renewable Energy:

<http://www.eren.doe.gov/RE/hydrogen.html>

The Renewable Energy Policy Project:

www.repp.org

The California Fuel Cell Partnership:

www.fuelcellpartnership.org

The Argonne National Laboratory:

<http://www.hydrogen.anl.gov/fuelcells/index.html>

The US Fuel Cell Council:

www.usfcc.com

National Fuel Cell Research Center, Univer- sity of California, Irvine:

<http://www.nfrcr.uci.edu/>



1 Congress Street
Suite 1100
Boston, MA 02114

EPA Energy Team Contact:

John Moskal
617-918-1826
moskal.john@epa.gov

manganate cathode and a nickel-zirconia anode. They are used for high-powered applications, such as industrial uses or central electricity generating stations. SOFCs are also being developed for use in automobiles^B taking the place of generators and alternators. They currently operate at very high temperatures of 800 - 1000 degrees C, and at efficiencies of 55 - 65%.

• Alkaline

The alkaline fuel cell uses an alkaline electrolyte such as potassium hydroxide. Originally used by NASA on space missions, it is now used for applications in hydrogen-powered vehicles. They operate with efficiencies of 50-60% in converting chemical fuel to electricity and are relatively inexpensive since they do not require platinum as a catalyst. They emit small amounts of CO₂, and operate at temperatures between 60-90 degrees C.

• Molten Carbonate

The molten carbonate fuel cell uses a molten carbonate salt as the electrolyte. It has the potential to be fueled with coal-derived fuel gases or natural gas. They operate at efficiencies of 60-65% and at temperatures of 620-660 degrees C.

• Zinc/Air Fuel Cell

These units combine zinc and air to form electrons and zinc oxide. The zinc-oxide is recycled to zinc pellets in the regeneration process. They operate at lower temperatures than other types of fuel cells. In the recycling process, using electricity from the utility or an alternative source, the

chemistry is reversed and the same oxygen is released back into the atmosphere, leaving pure zinc pellets in the electrolyte to be used as fresh "fuel." No pollutants are emitted. These cells can be used for a range of applications from backup power for telecommunications, networking and HVAC to portable power for field locations and emergency operations.

The cost of fuel cells

Because the fuel cell industry is still in an early developmental stage, sufficient information about the costs of electricity generation for stationary fuel cell units is not yet readily available. The U.S. Department of Energy is currently funding studies to gather data for long term costs per kWh of fuel cell unit power plants. It is expected that as the fuel cell industry matures, electricity generation costs will lower significantly.

Fuel cell engines & generators vs. gasoline engines & generators

- In the US, passenger vehicles alone consume 252 million gallons of oil a day. If 10,000 vehicles were to be powered by fuel cells, oil consumption would be reduced by as much as 6.98 million gallons per year.
- According to the DOE, if 10% of automobiles in the US were powered by fuel cells 60million tons of CO₂ would be kept from entering the atmosphere.

Emission Comparisons

- Emissions associated with electricity production:

Generator Type	NO _x (lbs/MWh)	SO ₂ (lbs/MWh)	CO ₂ (lbs/MWh)
Coal	>5	13.4	>2,000
Oil	>5	11.6	>2,000
Solid Oxide Fuel Cell	.01	.005	950

- Tailpipe Emissions by vehicle type:

	Natural Gas Fuel Cell	Methanol Fuel Cell	Gasoline Hybrid Electric	Gasoline ICE
VOCs*	0	.1	.4	.68
NO _x *	0	0	.6	1
CO*	0	0	6	10
CO ₂ equivalent*	96.61	257.6	241.5	402.6

* grams/mile